THE ORIGIN OF COMETS.

We find among men of science a singular mixture of caution and daring, degenerating sometimes into timidity on the one hand, and into rashness on the other. The scientific caution of a Newton, testing the theory of gravitation by line and measure, and calmly resigning it for awhile, because, as it chanced, line and measure were both inexact, may be compared with the noble daring of a Halley, boldly announcing that the comet of 1682 would return in 1758 * on the strength of observations which, in our day, would certainly be thought insufficient to determine a comet's period. The timidity with which the profound reasoning of Olmsted respecting meteors was rejected, till simple observations made that obvious which he had made certain, may be contrasted with the rashness shown by those who have accepted the speculations of Laplace about the universe as though these were demonstrated theories.

Comets, the most mysterious of all the bodies known to astronomers, have been subjects of most marked timidity and of most daring rashness of scientific reasoning. That men should have been unwilling to formulate definite theories about these wild wanderers is, perhaps, natural enough. But the calm, uninquiring confidence with which ideas have been advanced and suggested respecting comets is not so easily explained. One of these ideas, regarded by many as if it were an established truth, I propose now to inquire into,—the idea, namely, that comets have been drawn from those paths on which they chanced

* I am quite aware of the fact that the comet really returned in 1759, that is to say, that it was in 1759 that the comet passed its point of nearest approach to the sun. Halley's prediction, however, named 1758, and made as it was when the theory of gravitation was in its babyhood, it was a very fair guess.

originally to approach our solar system, by the perturbing influences of the giant planets, and have thus been, in certain instances, compelled to travel around the sun in elliptical paths, instead of the parabolic or hyperbolic orbits on which they had been traveling before they were thus captured. I think I shall be able, first, to show that this theory is antecedently most unlikely; then to prove that even if it had been the most natural and probable theory conceivable, it is entirely inconsistent with observed facts, and, therefore, untenable. I shall then suggest a theory in its place which, were I to mention it just here, would probably be rejected at once as the wildest speculation imaginable. Possibly, introduced as it will be by a series of observed facts not otherwise explicable, it may not seem so repellent a little further on. But I shall ask the reader interested in matters cometic, not to turn to the end of this essay until he has read the beginning.

We start from the conception that all comets originally entered our solar system from without. They come, say Heis, Schiaparelli, and others, who have advanced the Capture Theory, from out of interstellar space. Now, it is no valid objection to this view that it gives us no idea how cometary matter came to exist in interstellar space, for in all inquiries into the past condition of the celestial bodies we must always come short of their actual origin. Thus, in considering the past of our solar system we may start from a chaotic vaporous state, or from a past condition in the form of cosmical dust, or from a condition in which the vaporous and the dust-like forms are combined; but if we are asked whence came the vapor or the cosmic dust we are obliged to admit that we cannot tell. If, hereafter, we should be able to say that it came from such and such changes in a quantity of various forms of matter, which we may represent by X, Y, and Z, we should still be unable to say how X, Y, and Z came into existence. So that I make no serious exception against the supposed origin of comets on the ground that it really leaves very much to be explained. Interstellar space is a convenient place to which to assign the origin of bodies so mysterious as comets. *Cela exprime beaucoup de choses.* Almost anything might happen in regions of which we know so little, or, rather, of which we know absolutely nothing.

Yet it may be worth while to remark that, on the whole, the interstellar regions are less likely to be the regions whence

comets originally came to visit suns and sun systems, than to be regions whither comets strayed after leaving originally the neighborhood of solar systems. The most probable idea about the interstellar spaces is that they are the most vacuous regions within the range of the sidereal system. The mere circumstance that comets came from out of them affords no better reason for regarding them as the original home of comets, than the circumstance that comets pass from the solar system into these interstellar spaces affords for rejecting that assumption. There is, in fact, simply no reason whatever for imagining that the place where comets came into existence is the vast unknown region around the solar system which we call interstellar space. Most comets come to us from thence; as many comets are traveling into that unknown region as are coming out of it. To form an opinion about the origin of comets from no better evidence than their last journey (out of millions, very likely) can afford, would be as absurd as for a day-fly to reason that the river flowing past the home of his race came out of the sky because a few drops of rain came thence.

Suppose, however, we admit that in interplanetary space there have been in the past, and still exist, such flights of meteoric matter as the theory we are considering assumes. Let us grant them, also, such motion as may save them from what otherwise would inevitably be their fate, viz., a process of direct indrawing toward the nearest sun, and consequent destruction (with mischief probably to his orb), after a period of time which must be regarded as utterly insignificant compared with the time intervals measuring the duration of a solar system.

It follows, then, that each flight of meteors would, in the long run, draw near some sun, without, however, rushing directly upon him; and, sweeping round his globe upon such path as chanced to result from the combination of its original movement and his attractive influence, would pass out again into interstellar space. This might happen tens, hundreds, thousands, or even millions of times, a comet either sweeping in a long elliptical orbit, with enormous periods of revolution, around one sun; or, if its velocity were slightly greater than that supposition implies, rushing first round one sun, then out into the depths of space to visit another sun, then to yet another, and so on, flitting from sun to sun forever, or until the kind of disturbance in which the holders of the theory we are considering

believe, had changed this kind of motion into actual orbital circuit.*

In either case the minimum velocity with which a comet would be moving, when at any given distance from our sun, would be determinable within a few yards per second. It is well known that the velocity with which a body traveling to the sun from an infinite distance (though one cannot, of course, conceive such a movement) would reach the sun, would not exceed by a foot per second the velocity with which a body would reach him after traveling from the distance of the nearest fixed star. So also the velocities of bodies moving in orbits reaching half as far from the sun as the distance of the nearest star, would be the same within a foot or so per second as the velocities with which bodies coming to the sun from infinity would reach the same distance from him. If such bodies had originally a great inherent velocity, of course they would reach any given distance from the sun with much greater velocity. But this would not affect our estimate of the least velocity at that distance. Thus we know what the giant planets to which has been attributed the final capture of those comets which now form a part of the solar system, had to do. We can tell the precise velocity in miles per second, or, at least, the minimum velocity, with which our imagined meteoric flight would cross the orbit of Neptune, or Uranus, or Saturn, or Jupiter, as the case might be, before its capture. We know, in the case of each comet supposed to have been captured, the precise velocity of the comet at the distance of the planet which captured it,—its special planet-master. The difference is the amount of velocity which the capturing planet had to take away in order to effect the supposed capture.

Observe that we are here on sure ground, if the theory is sound. It is certain that a comet in coming from remote interstellar space to the solar system would have at the distance, say, of Jupiter, a certain velocity. It is certain that a comet now traveling in a particular orbit, approaching at one point very near to the orbit of Jupiter, has at Jupiter's distance a certain velocity, very much smaller. Hence, it is certain that, if Jupiter captured that comet by disturbing it as it approached

* I have here considered only two kinds of cometic orbit, the elliptic and the hyperbolic; for a true parabolic orbit would be as unlikely, or rather as impossible, as a truly circular orbit among the planets.

him on the last of its many free visits to the sun, the giant planet must have deprived the comet of so many miles per second of its former velocity. All we have to do is to find out how the planet could do this; in other words, how near the comet must have approached the planet to be thus effectively disturbed.

These pages are not suited for the close and exact discussion of the case of any particular comet. I have elsewhere (in a paper which appeared in the "Proceedings" of the Astronomical Society) given the details for certain cases which have been regarded as among the most satisfactory illustrations of the comet-capturing ways of the giant planets, and have shown that the theory is in those cases, and therefore in all, absolutely untenable, though so resolutely held. Still it may be well here to consider an illustrative general case,— the simplest that can be taken, and also the most effective, because the conditions are, in reality, much more favorable than they are in any known case.

Imagine a flight of meteors to travel from interstellar space toward the sun until it reaches the distance of Jupiter, and that when at that distance it chances to pass very close to the orbit of Jupiter, and at a time when Jupiter himself is very near the place where the meteor flight crosses his track. Observe that the chances against each one of these contingencies are enormous. If we conceive a sphere around the sun, girdled by Jupiter's orbit, the meteor flight in its course sunwards might traverse the surface of that sphere (or, which is the same thing, might traverse the part of its course where it is at the same distance as Jupiter from the sun) anywhere, and we are supposing that it traverses that surface close to a particular girdling circle (technically a "great circle" of the sphere). Suppose that by "close" we mean within a million miles; then the imaginary girdle of the sphere through which the meteor flight must pass to fulfill the required conditions is two millions of miles broad. The sphere itself has a diameter of some nine hundred and sixty millions of miles, and by a well-known property of the sphere,* its surface is four hundred and eighty times greater than that of the girdling strip. The chance is but one in four hundred and

* The property is this: that the surface of a sphere exceeds the surface of a girdling strip, such as we are considering, in the same degree (if the strip is relatively narrow) that the diameter of the sphere exceeds the breadth of the strip.

eighty that any meteor flight coming from interstellar space toward the sun will be within a million miles of Jupiter's orbit when at Jupiter's distance from the sun. Then Jupiter's path has a circuit of more than three thousand millions of miles. Thus the chance that at the moment of the meteor flight's passing the orbit, Jupiter will be within a million miles on either side of the place of passage, is as two in three thousand, or one in one thousand five hundred. But the chances that both these relations hold is only as one in one thousand and five hundred multiplied by four hundred and eighty, or as one in more than seven hundred thousand. Thus, assuming — though the case is otherwise — that a million miles would be an approach near enough for capture, still only one meteor flight out of seven hundred thousand which came from outer space could be captured by Jupiter.

This, however, is but the mere beginning. We may admit that millions of times as many comets or meteor flights approach our system as the planets have captured; and if so, we need recognize no special force in any such considerations as have just been presented. I only advanced them to suggest the conditions which are, as it were, essential for the process of comet-capturing by a giant planet.

Arrived at Jupiter's distance from the sun, the meteor flight from interstellar space will have a velocity of about eleven miles per second. Now let us inquire what its velocity must be reduced to in order that it may thenceforth be compelled to travel in a circle around the sun. As a matter of fact, all the members of Jupiter's comet-family travel in orbits whose remotest parts are near Jupiter's orbit, and to give a comet such an orbit as one of these much more must be done in the way of reducing velocity than is necessary merely to make the meteor flight from outer space travel thenceforth in a circle at Jupiter's mean distance. We are taking, in fact, a very unfavorable case for our argument. Still, the velocity must be reduced, even in this case, by nearly three-tenths, or by more than three miles per second.

Now Jupiter's power to withdraw velocity from a body in his neighborhood is measured by his power to impart velocity. In fact, both processes are but different forms of the same kind of work. Precisely as we say that the sun can communicate a velocity of three hundred and eighty-two miles per second to a

body approaching him from interstellar distances, and that therefore the sun can withdraw such velocity from a body leaving his surface at that rate, and eventually bring such a body to rest out yonder in interstellar space, so can we make a corresponding statement for any planet,—Jupiter or Saturn, the Earth, our Moon, and even for the least of all, the asteroidal family (supposing only the mass and size known). In the case of Jupiter, for instance, we find that the utmost velocity he can impart to a body reaching him from external space is about thirty-six miles per second. That, at least, is the velocity with which such a body would reach the visible surface of the planet. What the velocity might be with which the real surface, far down below the visible envelope of clouds, would be reached, we do not know,—not knowing where that surface lies. In the case of our own earth, the velocity with which a body would reach the surface, if brought thither solely by the earth's action from interstellar space, would be a little over seven miles per second, or more than twenty-seven times greater than the velocity of the swiftest cannon-ball.

But while Jupiter — to keep for the moment to our giant planet — has thus, theoretically, the power of giving or taking away a velocity of thirty-six miles per second, he is not practically able to do anything of the sort. He is not left to draw matter to himself, or to act on the recession of matter from himself, alone. The bodies which come near to him from outer space have been drawn by solar might within that distance from the sun, and almost the whole velocity they there possess is sun-imparted. We have seen what it is,— some eleven miles per second. Now, manifestly, this greatly affects Jupiter's power of imparting or withdrawing velocity. Both processes require time, and it is clearly impossible for Jupiter to produce anything like the same effect on a body rushing past him with a sun-imparted velocity of eleven miles per second as he would produce on a body left undisturbed to his own attraction. Jupiter's action at any moment is the same whether the body is moving or at rest; but the number of moments is very much reduced owing to the swift rush of the body past the planet. To use the old-fashioned expression of the first students of gravitation (an expression which has always seemed to me amusingly quaint) the solicitations of Jupiter's attractive force are as urgent on a swiftly rushing body as on one at rest; but

if a body will not stay to hearken to them much less effect must be produced. In all this part of my reasoning, I may remark, I am not pleading a cause, but indicating what every student of celestial dynamics knows.

We may fairly regard twenty-five miles per second as the utmost velocity that Jupiter can impart or take from any body coming out of interplanetary space past him, as close as such a body can pass without being actually captured. Moreover, in every possible case, Jupiter can only abstract or add a small portion of this amount; for this reason, simply, that in every possible case there will be first an action of one kind (abstraction or addition of velocity), and afterward an action of the opposite kind (addition or abstraction respectively). It will be but the difference between these effects, in most cases very nearly equal, which will actually tell on the body's future period of revolution around the sun.* This makes an enormous reduction on Jupiter's potency to modify cometic revolution. Certainly ten miles per second is a very full estimate of the velocity he can abstract or add in the case of a body passing quite close to his apparent surface.

But even this may seem ample. Seeing that a loss of three miles or so per second would cause a body which had reached Jupiter's distance from the sun, after a journey from out of interplanetary space, to travel in the same period around the sun as Jupiter himself, and since we seem to recognize a power in Jupiter to abstract ten miles per second, it would seem as though Jupiter's capturing power were in fact demonstrated.

But while, to begin with, the close approach required for this capturing power to exist is something very different from that approach within a million miles which I before considered, there is a much more important difficulty to be considered, in the circumstance that we have thus far dealt with Jupiter's capturing power on one body, not on a flight of bodies, such as a comet approaching from interstellar space is held to be, according to the theory I am discussing. Let us take the former point, though the least important, first.

At Jupiter's apparent surface the actual maximum velocity which the planet could give to a body approaching from a

* As distinguished from the orbit. The orbit might be largely affected even in a case where the velocity at Jupiter's distance remained absolutely unchanged; but in this case the period of revolution would remain the same.

practically infinite distance would be about thirty-six miles per second, and we reduced the actual maximum effect on a body passing Jupiter very close, under such conditions as actually prevail in the solar system, to ten miles per second. Let us see what would be the corresponding numbers in the case of a body passing within a million miles of him, remembering that even that would carry such a body right through Jupiter's system of satellites, the span of that system being about four and a half millions of miles. Since a distance of one million miles exceeds the distance of Jupiter's surface from his center nearly twenty-five times, it follows (I need not explain why, mathematicians will know, and for non-mathematicians the explanations would be tedious and difficult) that the velocities which Jupiter can give or abstract at the greater distance would all be reduced to little more than one-fifth those determined for Jupiter's surface. So, instead of ten miles per second, we should get but two miles per second, as the greatest Jupiter could abstract from a body approaching him within a million miles. And this would not be sufficient reduction to make such a body travel thenceforth in Jupiter's period, still less in one of the much shorter periods observed throughout what has been called Jupiter's comet-family.

But the other difficulty is altogether more serious. A comet approaches Jupiter, on the theory we are dealing with,—and indeed the same may be assumed on any theory,—as a flight of scattered bodies. Either this flight is so close as to be in effect, because of mutual attractions, a single body, or it is not. If it is, the flight will not be broken up by Jupiter's action; and, if not so broken up, will remain forever after a united family. But if, as is more in accordance with observed facts, the cometic flight is so large that the attraction of the flight, as a whole, on the separate members, can be overcome by Jupiter's action, then not only will the flight be broken up, but the orbits given to different members of it by Jupiter's disturbing action will be widely different. Suppose, for example, the extent of the flight to be such that the parts coming nearest to Jupiter approach his center within fifty thousand miles (a very close approach, indeed, to his surface), while those parts which are remotest from him at the time when the flight, as a whole, is nearest, came only within sixty thousand miles from his center. Then, in round figures, the reduction of velocity of the nearer members

of the flight will be greater than the reduction for the farther members, as six exceeds five. Supposing, for argument's sake, the former reduction to be three miles per second, as it must be to make those members of the flight travel thenceforth in Jupiter's period round the sun, then the reduction for the outermost members would be but three and a half miles per second; or thenceforth one set of meteors formerly belonging to the comet would have at Jupiter's distance a velocity of eight miles per second (eleven less three), while another set would have a velocity of eight and a half miles per second (eleven less two and a half) at that distance. This means that thenceforth the mean distance of the latter set from the sun would exceed the mean distance of the former set about as nine exceeds eight.* Since the former set would thenceforth be traveling at Jupiter's distance, or about 5.2 times the earth's, the latter set would be traveling at a mean distance greater by one-eighth of this, or .65 of the earth's distance, say some sixty millions of miles. The latter set would be at their nearest to the sun when at Jupiter's distance, would pass sixty millions of miles farther away to their mean distance, and as much farther away still at their greatest distance. Practically, then, even in this case, as favorable for capture as can be well imagined, the capture, though effected, would result in spreading out the comet, which had arrived as a compact flight of meteors ten thousand miles only in span, over a region one hundred and twenty millions of miles broad. It is hardly necessary to say that nothing like this is observed in the case of any member of Jupiter's comet-family. We know that along their track meteors are strewn to distances which, in some cases, may well exceed even the enormous distance just named; but they lie along the track, not ranging more than a few hundred thousand miles on either side from the path of the comet's head. This means that the orbit of every single meteor of such a system has, practically, the same mean distance from the sun.

The difficulty last considered is simply fatal to the theory that the comets forming what have been called the comet-families of the giant planets were captured by those orbs in the

* The simple law is, that for two bodies having different velocities at the same distance from the sun, the mean distances from him differ as the square of those velocities. Now, the square of eight and a half is seventy-two and a quarter; that of eight is sixty-four.

way imagined by Heis, Schiaparelli, and others. We must seek for a different explanation, if we are to account for the peculiar relations of these comet-families at all. It may be that the peculiarity, like many others presented by comets, may not admit of being explained. The considerations I am about to advance may to many appear not altogether convincing; nevertheless, as they involve the study and discussion of known facts, they are worth investigating, quite apart from all questions of the validity of the theory with which I associate them.

Observing that the giant planets have each their comet-family, we may safely infer that the sun also has his special family of comets; that is, a family the dominion of which he does not in any sense share with the giant families. The comets which we should thus regard as specially solar are those whose paths approach exceptionally near to his globe. Among numbers of comets which come from out of interstellar space toward the sun, and, sweeping around him, pass away again into the depths from which they came, many have paths passing so far from his globe that we cannot regard them as in any special way associated with him. Bodies coming casually, so to speak, from outside regions would have just such paths. So that of many comets, not belonging to the comet-families of the giant planets, we may say that neither do they belong to the comet-family of the sun. Yet even these teach something. Whatever theory we adopt as to the origin of comets, it must give an account of these comets, as well as of those which, passing very near to the globe of the sun, may be regarded as belonging specially to him, and those others which we assign as the special dependents of the giant planets.

Now, taking the two last-named classes, we recognize in the movements of the members of each class evidence of the introduction of these comets into the solar system, through the intervention, in some way, (1) of the giant planets in the case of one class, and (2) of the sun in the case of the other class. We have seen that the giant planets could not have introduced their comet-families from out of interstellar space by perturbing influences. We may infer with almost equal probability, or almost with certainty, that neither did the sun introduce his comet-family by drawing them from out of interstellar space.

Since, then, the sun and the giant planets did not introduce their special comet-families from interstellar space, yet did most

manifestly introduce them in some way, where else can these comets have come from but from within the orbs of the sun and of the giant planets respectively?

At first sight this theory seems so strange and fanciful that we are almost deterred from examining it further by its apparent grotesqueness. We seek about for a way of escape from so wild a theory. We look back to a remote period when, in accordance with the ideas of Laplace, the sun's mass extended far beyond the present orb of the sun, and the giant planets also had orbs extending even as far as the orbits of their outermost satellites. Undoubtedly, if a flight of meteors in that far distant period rushed through the outer vaporous surroundings either of sun or of giant planets, the effects imagined by Schiaparelli and by Heis might have been produced. The diminution of the velocities of the meteors forming such a flight might well be far more effective than in the case we have hitherto considered, of free space around a planet's globe.

But we may regard this theory respecting the introduction of comets into the solar system as one which may wait its turn until the other, of ejection, strange and fanciful though it may seem, has been examined. For there is nothing in the capture theory, considered in itself, to invite us specially to its adoption. It gives no account whatever of the actual origin of comets. It only suggests how, having somehow come into existence in interstellar space, comets would be drawn sunward, and might be captured by the sun or by planets. If to this inherent difficulty in Schiaparelli's theory we are to add all the difficulties involved in the supposition that the sun and the giant planets were once much larger than they now are, and that being thus large they were able to capture comets by actual interruption of their movements, we may at least consider that before discussing such views, before attempting to carry back our thoughts over the practically interminable time intervals involved in such a process, it may be well to examine a theory which, though startling at a first view, promises to explain something more, if confirmed, than the scarcely less startling theory of comet capture by expanded sun and by expanded planets.

Suppose that instead of looking into remote regions of space, and toward far off periods of time, we examine meteoric masses, and inquire of them whence they came. We cannot expect each meteorite to have a story to tell; but after a goodly number

have been examined, we may light upon one speaking with tolerable clearness respecting its origin. Our first studies shall be with the microscope.

Now, passing over a number of microscopic studies of meteorites which are suggestive enough, but not decisive, we come on the strange fact that certain meteorites show under the microscope the clearest evidence of having once been in the form of tiny globules of molten metal, numbers of which have become agglomerated together. The eminent microscopist and mineralogist Sorby, of Sheffield (England), asks respecting these particular meteors, where else could they possibly have existed in the form of metallic globules (liquid) except in the interior of a body like the sun? In the interstellar spaces intense cold prevails. In rushing close past the sun a meteoric mass might be molten, but would scarcely be vaporized, even though the orbit of the flight passed very near the sun's surface. But the meteorites which have visited our earth have not been associated with comets passing near to the sun. Manifestly the chances are very small that any meteorite following in the train of a comet like Newton's or the comet of 1843—that is, a comet traveling close past the sun — would ever reach the earth. But Sorby found microscopic evidence such as I have described in quite a large number of meteorites which he examined.

At any rate, the assumption for the moment, that such meteorites had their origin within the interior of a body like our sun, accords well with the theory we have had suggested to us, that comets and meteor flights (kindred bodies) came from within the orbs with which we still find them associated.

Turn now to the chemical analysis of meteorites. Here the evidence is perhaps even more suggestive. Masses of meteoric iron being placed under the air-pump, hydrogen which had been present in their substance —occluded in the iron, as it is technically expressed — has come out in such quantities that Professor Graham (of London) considers the amount fully six times as great as could be occluded in the substance of iron by any process known to chemists or physicists. This Lenarto meteor, he says, has brought to us across the interstellar spaces the hydrogen of the fixed stars. In other words, Professor Graham could see no other interpretation of the presence of so much hydrogen within the substance of this mass of meteoric iron than that the hydrogen had been forced into the iron while yet within the

interior of a star. We know that beneath the visible surface of our sun there must be both the vapor of iron and hydrogen at enormous pressure. Under such conditions alone could masses such as the Lenarto meteorite be formed. Professor Graham, therefore, assumed confidently that the Lenarto meteorite and others of the same sort were formed in the interior of a body like our sun. He rejected, rightly, the idea that it was in our sun himself that the meteorites of that class were formed. For the chance of any meteorite ejected from the sun reaching our earth is but about as one in twenty-two hundred millions. The greater number of the sun-ejected meteorites he saw must have been ejected from the interior of the other suns which people space. There are hundreds of millions of such suns even within the range of telescopic vision; millions of millions doubtless exist; so that if we once admit the possibility of the ejection of meteoric masses from within a sun or star, we recognize the probability, or rather the certainty, that there must be billions of billions of such masses traveling amid the interstellar spaces.

All this was reasoned out thus before it had been shown that suns ever do eject masses with sufficient energy to carry them beyond the attractive influences of their parent orbs; nay, Sorby and Graham expressed their views respecting the origin of some meteorites when it seemed utterly unlikely that we ever should get evidence of stellar eruptive powers which that theory requires.

But such evidence has now been obtained. Professor Young, of Princeton, N. J. (then of Dartmouth, N. H.), was the first, in 1872, to obtain evidence of the actual ejection of matter from the sun's interior with velocities sufficing to carry such matter forever away from him; but the evidence was decisive, and since then kindred observations have been frequently made. What Young saw, indeed, was apparently the ascent of filaments of hydrogen, at an average rate of nearly two hundred miles per second; but it was easy to see that the irregular streaks of hydrogen were not themselves the ejected matter. If a thin gas like hydrogen could rush through the region immediately above the sun's visible surface at the rate of two hundred miles an hour,—which I reject as incredible,—the shape of such hydrogen missiles would be such as to indicate very clearly the resistance they were encountering. They would be pear-shaped, the rounded part of the pear in front, like fire-balls in our air.

But these were irregular streaks, like the luminous tracks of meteors, and such doubtless they were. A flight of masses of considerable density must have been shot out on that occasion, and on other occasions when similar phenomena have been observed, and rushing through the hydrogen in the sun's neighborhood, caused the gas to glow along their track, just as fireballs in our air leave behind them long luminous trails. The rate at which these missiles advanced could be inferred from the rate at which the luminous trails followed them. Calculation, in which the sun's retarding action was taken duly into account, showed that the matter thus expelled from the sun left his surface at a rate of not less, probably, than five hundred miles per second. The ejected matter left the sun, then, never to return, and in the form of precisely such a flight of meteoric missiles as microscopic and chemical researches had shown to be traveling through the interstellar spaces.

When we consider the three lines of evidence, and note how independent they are of each other, we see that the theory of the ejection of masses akin to meteors from the suns which people space is rendered all but certain independently of any line of *à priori* reasoning which had led us to look for evidence of such processes. Certain meteors have shown under microscopic study that they were certainly once in a condition such as could hardly exist except in the interior of a body like the sun; others have shown under chemical analysis that they must have been ejected from the interior of a sun; and now we have evidence showing that from our sun, and therefore presumably from his fellow-suns, the stars, flights of missiles akin to meteoric bodies are ejected from time to time with velocities sufficient to carry them into interstellar space. It seems reasonable to infer that here we have the solution of our difficulty; we see that the sun, at any rate, has power to eject at times from his interior flights of meteoric masses, such as we recognize in the streams of meteors which exist within the solar system, and that the velocity of outrush is in some cases so enormous that the masses thus ejected can never return to the sun, but pass away through interstellar space. We find also that meteoric streams, which we are thus led to associate with the solar eruptions, are also associated with comets, every known meteoric stream traveling, probably (as many certainly do), in the track of a comet. Now, knowing the small masses of many comets, it is no very wild thought to sug-

gest that those comets whose present orbits carry them close to the sun were originally expelled from his own interior. Assuredly the flights of missiles which we know to be at times driven from his interior are in all respects akin to what we know many comets actually to be, akin in structure, akin in mass, and akin probably in condition. For in whatever respects the coma and tail of a comet may seem unlike mere meteoric masses, we know that such peculiarities of condition are due to solar action, and that a flight of meteoric masses ejected from the sun himself would as certainly present these peculiarities under subsequent solar influences as any other flight of meteoric masses not ejected originally from the sun.

May not this reasoning be extended to the giant planets, either in their present demonstrably somewhat sunlike state, or in those past stages of their career when they were veritable suns, though small ones? In the great red spot of Jupiter, however, we have had evidence of even a present intensity of eruptive action by which meteoric and cometic matter might well have been ejected in such sort as to pass forever beyond the control of the giant planet. At any rate, the great disturbance suggests, by parity of reasoning, that within comparatively recent times Jupiter and Saturn have possessed the necessary expulsive power. It must be remembered that thus to eject matter with velocities sufficient to carry it forever away, Jupiter and Saturn would not need anything like the same ejecting power which the sun has to exert to expel matter forever from within his globe. They are much weaker than the sun, but for that very reason they would need to exert much less eruptive force, seeing that it is their own attractive power they have to overcome, and that that is weaker in even a greater degree than probably is their eruptive power.

Now, there is a family of comets attending in a sense on Jupiter, and another family attending similarly on Saturn, precisely as we should expect them to do if originally expelled from the interior of these planets. After such expulsion, though free to pass away forever from their parent planets, they would not be free to pass away forever from the solar system. They would be thenceforth attendant on the sun, but with this peculiarity, that no matter what perturbations they underwent, their paths would always pass near to the path of their parent planet. Even if in some future circuit a comet of this sort came quite

close — as it very well might — to the planet it originally started from, it would still, though very much disturbed, follow a path possessing this characteristic, however different from the path which it had before traversed. After many millions of years, indeed, it might happen, perchance, that resistance encountered in its movement around the sun, however ineffective to affect its orbit appreciably in a few thousands of years, would reduce the span of its circuit. But even then it would still be possible to classify a comet whose orbit had been so changed with the family of comets to which it had originally belonged.

Now we find that among the periodic comets attending on the sun nearly all belong to families which have long since been relegated to the giant planets. There is a family of comets every member of which has an orbit passing very near to the orbit of Jupiter; another family every member of which can be similarly associated with Saturn; others depending in the same way on Uranus; others on Neptune; and, in fact, so fully has this sort of relation been recognized that the idea has been thrown out that a planet traveling outside the orbit of Neptune, but as yet unknown, might be detected by the movements of a comet intersecting the great plane of planetary movement far beyond Neptune's orbit. It may be mentioned, indeed, in passing, that the comet of 1862, which has been associated with the meteors of August 10 and 11, intersects the plane of planetary movements at a place about as far beyond the orbit of Neptune as that orbit is beyond that of Uranus; and that it has been held probable that at that distance a giant planet as yet undiscovered may travel.

The existence of the comet-families of the giant planets can scarcely be explained without assuming that which we have thus been led on another line to recognize as probable,—the ejection from the giant planets of masses of matter, in eruptions akin to those taking place in the sun. Whether such eruptions take place now in the giant planets, or not, would be difficult to prove; for although we have evidence of tremendous disturbances, we have nothing to show conclusively that these would suffice to eject matter forever from within these planets' globes. Whether a careful study of the region outside the disks of Jupiter and Saturn (the planets themselves being hidden by opaque disks) would decide the point I am not prepared to say; but I am certain that the edges of the disks of the giant

planets are worth much more careful study than they have yet received.

But undoubtedly most of the comets of Jupiter's family must have been added to the solar cometic system hundreds of thousands if not millions of years ago. Quite possibly both Jupiter and Saturn still eject matter from time to time with such velocities from their interiors that it passes away never to return to them. In this, as in many other features, Jupiter and Saturn are still somewhat sunlike. But they have passed their truly sunlike youth. They tell us of what our own earth was like when she was young. We may trace back her history, however, even to the sunlike state. The same law which we applied to the giant planets may be applied also to her. Her eruptive energies must have been very much less active, even in her sunlike youth, than those of the sun now; but the force against which she had to work (her own attractive energy) was much less potent, too, nay, may probably have been less potent in even greater degree. Just as the moon in her volcanic youth upheaved her surface much more than the earth upheaved hers, because, though the moon was weaker, her subterranean energies had so much smaller downward tending action of gravity to contend against, so it may well be that the smaller a planet when in its sunlike state, the more easily did eruptive forces eject matter beyond the range of the planet's attractive forces. In this case every planet at that stage of its career, as well as every sun, gave birth to cometic and meteoric systems, each after its own kind; solar comets being large ones like those which astronomers have not been able to associate with the planets' comet-families; the comets ejected by the giant planets coming next in order of size; and the comets ejected by smaller orbs, like the terrestrial planets, moons, asteroids, and so forth, being probably too small to be discerned even with telescopic aid.

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